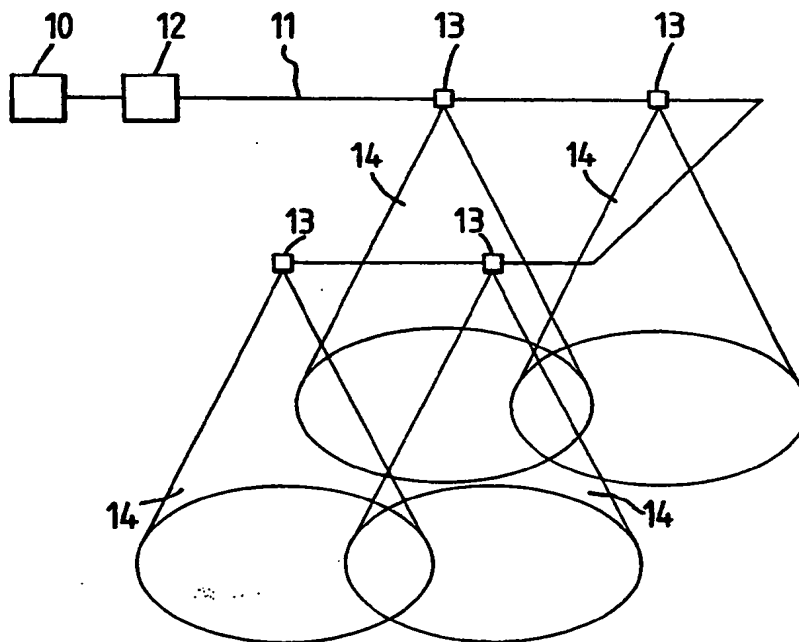




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<b>(21) International Application Number:</b> PCT/GB93/01590 <b>(22) International Filing Date:</b> 28 July 1993 (28.07.93)  <b>(30) Priority data:</b> 92306885.2 28 July 1992 (28.07.92) EP <b>(34) Countries for which the regional or international application was filed:</b> AT et al.  <b>(71) Applicant (for all designated States except US):</b> BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY [GB/GB]; 81 Newgate Street, London EC1A 7AJ (GB).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only) :</b> CASSIDY, Stephen, Anthony [GB/GB]; 79 Humber Doucy Lane, Ipswich, Suffolk IP4 3NU (GB). SMYTH, Peter, Paul [GB/GB]; The Old Piggery, Mill Road, Newbourne, Woodbridge IP12 4NP (GB). WILLIAMS, Douglas, Lawrence [GB/GB]; 2 Laurel Cottages, Rosehill, Grundisburgh, Suffolk IP13 6TF (GB).		<b>(74) Agent:</b> BROOKES & MARTIN; High Holborn House, 52/54 High Holborn, London WC1V 6SE (GB).  <b>(81) Designated States:</b> AU, CA, GB, JP, KR, NZ, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.          Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** FREE SPACE OPTICAL COMMUNICATION SYSTEM**(57) Abstract**

An optical communication system for free space communication comprising an optical source including means to modulate the optical output to provide an optical signal, said optical source being connected to an optical fibre to pass said signal therealong, the optical fibre including antenna means comprising an optical fibre transmit portion comprising a core, and a cladding, said cladding including at least one substantially flat surface extending along its length and means to couple light out of the optical fibre through said substantially flat surface(s), and scattering means to scatter into free space light thus coupled out of the fibre.

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## Free Space Optical Communication System

The present invention relates to optical communication system.

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It is well known to use, for example, an infrared source to pass information, for example, a television remote control apparatus, or an infrared transmission system in a theatre for transmitting signals to a headset receiver for use, for example, by people with impaired hearing. Optical free-space transmission is the new alternative to radio and microwave communications for future mobile computer networks. It is capable of offering far greater bandwidth and, where it is used inside rooms where it is used, it does not interfere with other systems. These new infra-red communications systems could be based on very low-cost consumer optoelectronic components such as 850nm sources and silicon detectors. The projected cost of optical free-space wireless systems is therefore much lower than microwave-based systems. Low cost is fundamental to mass exploitation of communication systems for use with mobile computers.

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There are, however, several problems with such systems. Firstly they require power to be provided to the transmitter itself, and secondly, in some circumstances, it may be possible by the use of a lens, for example a binocular lens, (the diameter of the lens is defined in the standard to be 50mm) to focus the infrared radiation from the transmitter on to the skin, or worse still, the retina and to possibly damage the skin or retina.

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An important factor is the size of the optical source - the lens of the eye may focus the light from a point source to a small intense spot on the retina, whilst the same optical

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energy from a large area source will give a much larger spot on the retina and will thus result in less of a hazard.

5 Various national and international standards on the safety of lasers (such as IEC825 [2]) specify what optical emission levels from lasers should be considered as safe. In these standards, products are classified according to the hazard, with class 1 being defined as inherently safe  
10 (even when viewed with optical instruments such as binoculars). It will be necessary for optical wireless applications to fall into this category.

The increasing exploitation of wavelengths in the near-  
15 infra-red range for communications and other applications has stimulated more detailed examination of the biological damage levels for these wavelengths. The relevant optical wavelengths for LAN systems are about 850nm, 1300nm, 1480nm and 1550nm or other wavelengths where suitable emitter and  
20 detector components are available. In general, the maximum safe-power levels will be relatively low, near the visible part of the spectrum, because the eye is particularly efficient at focusing and absorbing the radiation. At wavelengths greater than 1400nm the retina is less at risk,  
25 but skin damage is still possible. Proposed changes, in Amendment 2 of IEC825, will incorporate relaxations to the safe-power levels at the relevant wavelengths. These changes will result in increases in maximum power for class 1 at 850nm from 0.24mW to 0.4mW, at 1300nm from 0.6mW to  
30 8mW, and at 1480nm and 1550nm from 0.8mW to 10mW. In addition, further analysis of the effect of light from large area sources has resulted in a new, more accurate, method of assessing the hazard, which is also planned to be included in Amendment 2.

Reference may be made to our copending EP 521 710A which is hereby incorporated by reference.

5 The present invention provides an optical communication system for free space communication comprising an optical source including means to modulate the optical output to provide an optical signal, said optical source being connected to an optical fibre to pass said signal therealong, the optical fibre including antenna means comprising an optical fibre transmit portion comprising a core, and a cladding, said cladding including at least one substantially flat surface extending along its length and means to couple light out of the optical fibre through said substantially flat surface(s), and scattering means to incoherently scatter into free space light thus coupled out of the fibre.

20 Preferably that said optical fibre transmit portion includes a coating surrounding said cladding.

25 Preferably the distance between said core and said surface and the relative refractive indices of the cladding and the coating is such that said optical signal from the optical fibre transmit portion is scattered into free space to provide incoherent scattered light outside the fibre.

30 Preferably the light from within the optical fibre is scattered through an angle of more than  $90^\circ$  to the direction of passage of light along the fibre.

Preferably the antenna means includes means to further incoherently scatter the light into free space.

35 Preferably the further scattering means includes a diffuser in the form of a diffuse screen or scattering lens

elements.

5        Preferably said scattering lens elements are lenticular elements formed by spraying transparent material on to at least one of said at least one flat surface and allowing individual droplets to set.

10       Preferably the further scattering means comprises glass beads.

15       Preferably the further glass beads have diameters in the range 3 to 18 $\mu$ m.

20       Preferably the coating is transparent to said light and said glass beads are provided within the coating on the outer surface of the coating or both.

25       Preferably the further scattering means comprises irregularities in the core of the fibre.

30       Preferably the irregularities comprise small crystals within the fibre core which provide Rayleigh scattering.

35       Preferably the further scattering means comprises a holographic element.

         Preferably said holographic element is formed on at least one of said substantially flat surface of said fibre.

         Preferably a plurality of said optical fibre transmit portions are provided at spaced intervals along the optical fibre.

         Preferably said spaced optical fibre transmit portions are arranged so that, successive portions are arranged to

transmit an increasing proportion of the available light in the fibre whereby the amount of light transmitted by each portion is substantially the same.

5 Preferably the optical fibre transmit portion is between 1 and 100m in length.

Preferably the optical fibre transmit portion is between 1 and 10m.

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Preferably the optical source is arranged to transmit 10mW to 1W of light along the optical fibre.

15 Preferably the optical fibre includes a dopant capable when stimulated of amplifying the signal from the source as the signal travels along the fibre.

20 Preferably the optical source and a pump source are connected to the fibre through a wavelength multiplexer the pump source providing a signal at a shorter wavelength than the signal from the optical source to stimulate the dopant in the fibre.

25 Preferably the source is a laser having a power output up to 200mW and in that the light transmitted from the optical communication system is arranged so that it is not possible, with a lens of up to 50mm diameter, to form the light to provide an energy density sufficient to damage a human as defined.

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Preferably the distance (d) between the periphery of said core and said substantially flat surface of the cladding is between approximately 5µm.

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Preferably the distance (d) between the periphery of said

core and said substantially flat surface of the cladding is approximately 5 $\mu$ m.

5 Preferably said cladding is surrounded by a coating of diameter in the range 250 to 400 $\mu$ m.

10 The invention also provides an optical communication system for free space communication comprising an optical source, including means to modulate the optical output from said source to provide an optical signal, said optical source being connected to an optical fibre to pass said signal thereto, the optical fibre including signal transmit means comprising an optical fibre transmit portion comprising a core, and cladding, the core including optically effective  
15 irregularities whereby some of said optical signal from the optical fibre transmit portion is scattered through the cladding to provide incoherent scattering into free space outside the fibre.

20 Preferably said irregularities comprise small crystals within the fibre core which provide Rayleigh scattering.

For the first time, the inventors have appreciated that in order to meet the safety requirement, it is desirable to  
25 (a) provide an extended source so that even with the use of, for example, a focusing lens, it is not possible to focus the light from the extended source so as to provide an energy density of radiation sufficient to damage a human (ie, less than 0.4mW, preferably less than 0.24mW at 850nm, less than 8mW, preferably less than 0.6mW at 1300nm, less than 10mW, preferably less than 0.8mW at 1480-1550nm) and  
30 (b) to provide incoherent scattering of the transmitted light there are no untoward concentrations of light transmitted to any spatial point.

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The use of an extensive source prevents light from all points along that extensive source being brought to a spot by any focusing means in a practical environment. If, for example, the extensive source is a metre long and across the ceiling of a typical room, say 2.5 metres above desk height, then the light from the extensive source cannot be brought to a spot. An image must be formed. The size of the image of the extensive source will depend upon the focal length of the lens in question. Generally speaking, the ratio of the size of the image of the extensive source itself to the size of the extensive source itself will be the same as the ratio of the focal length of the lens to the distance from the lens to the extensive image. To produce an image which can be brought within the pupil of an eye would require a lens, in these circumstances of extremely short focal length and therefore of very limited aperture. As a result, the amount of energy which can be collected by such a small lens is very limited. In other words, for larger sources, the power density on the retina, and thus the hazard, will depend on the power density incident on the cornea and the size of the source in terms of the angle subtended by the optical source at the eye. A more appropriate measure of light for safety purposes for these large sources is the radiance ( $\text{W/m}^2/\text{ster}$ ) of the source. As it is not possible for the radiance to be increased using an optical instrument, this value is a more fundamental measure with which to assess safety. For the wavelength 850nm, the maximum safe radiance for continuous viewing (IEC825) is  $12.8 \text{ kW/m}^2/\text{ster}$ . Assuming a large area Lambertian source (the distribution expected from a perfect diffuser), the radiance,  $L$  ( $\text{W/m}^2/\text{ster}$ ), is related to the power density on the emitting surface,  $H$  ( $\text{W.m}^2$ ), by  $L=H/\pi$ .

Therefore the maximum safe power density on the emitting surface will be  $41 \text{ kW/m}^2$ . For sources which give

distributions of power that are different from Lambertian, this power density will be scaled according to the total solid angle covered.

5 A value of  $41 \text{ kW/m}^2$  would appear to be very large to be considered as eye-safe, especially as it exceeds the MPE level for skin damage,  $2 \text{ kW/m}^2$ . Recently, there have been suggestions that the conditions specified in IEC825  
10 for dealing with large sources will appear in Amendment 2, and are likely to reduce this value considerably. Initial proposals indicate that the maximum safe power density from a Lambertian source for continuous viewing at a wavelength of  $850 \text{ nm}$  could be as low as  $0.37 \text{ kW/m}^2$ .

15 One way of providing an extended source is to use a D-fibre. This fibre is produced by removing a portion of the circular cladding at the fibre preform stage to give a D-shaped cross section with the core close to the flat of the  
20 "D". When the fibre is drawn the D-shape is maintained, and long lengths of fibre can be fabricated with the core only a matter of microns below the flat surface. Optical power is guided by this structure with low loss, providing the material in contact with the flat of the D-fibre has a  
25 lower reflective index than that of the fibre core. If a material with higher index meets the flat surface, light will couple from the core into the material overlaid. The rate at which the light couples out with distance is determined primarily by the distance from the core to the  
30 flat of the D-fibre. The refractive index of the overlay material determines the angle at which the light emerges, and, to a lesser extent, the coupling rate.

35 The overlay material can be formed by microlens or scattering surfaces on the D-fibre flat. The emergent

optical power can be made to cover wide angles with different inclinations to the fibre surface according to the application. The scattering features can be incorporated into the fibre or overlay materials themselves. These overlay materials may simply form the fibre coatings.

Amplifiers may be provided and the amount of light radiated from the end closest to the amplifier should be controlled so as to be of a suitable radiation density to comply with above described relevant safety standards, and yet at the same time is sufficiently high that power is still being radiated from the fibre at the end remote from the amplifier. This may require a continuous amplification system or amplifiers spaced along the length of the fibre.

In addition to this, by providing backward scattering of the radiated light (ie, making the scattering more Lambertian) the possibility of focusing sufficient light to harm a human can be further reduced and yet the amount of radiation overall radiated can be sufficiently large to be useful.

Such an optical communication system has widespread uses. For example, an optical fibre including such an arrangement may be provided across the ceiling of a room and it may be arranged so as to provide a diffuse pattern of light into the room, which light will carry a signal which may be picked up and utilised, for example, by radiation receivers forming part of televisions or computers which are thereby not directly connected to a signal source by hard wire. This is particularly convenient in auditoria, corridors, temporary rooms, and rooms of an unusual shape. Such an arrangement is particularly convenient as the televisions or computers may be moved around the room and continue to

receive the signal. Also because of the use of light, the band width is increased allowing simultaneous transmission of many signals.

5 Such an arrangement may also be used to transmit, for example, a signal such as a television signal remotely to one or more buildings.

10 In this specification the term "optical" and "light" are intended to refer to that part of the electromagnetic spectrum which is generally known as the visible region together with those parts of the infrared and ultraviolet regions at each end of the visible region which are capable, for example, of being transmitted by dielectric  
15 optical waveguides such as optical fibres.

Preferred embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings in which:-

20 Figure 1 is a diagrammatic view of a first apparatus according to the invention,

Figure 2 is a transverse section of a first arrangement of optical fibre in the region of a transmit means of Figure 1,

25 Figure 3 is a transverse section of a second arrangement of optical fibre in the region of a transmit means of Figure 1,

Figure 4 is a transverse section of a third arrangement of optical fibre in the region of a transmit  
30 means of Figure 1,

Figure 5 is a diagrammatic view of a second apparatus according to the invention,

Figure 6 is a diagrammatic view of a third apparatus embodying the invention,

35 Figure 7 is a transverse section of a fourth

arrangement of optical fibre,

Figure 8 is a transverse section of a fifth arrangement of optical fibre,

5 Figure 9 is a transverse section of a sixth arrangement of optical fibre,

Figure 10 is a graph of intensity detected by detector, against the detector angle from the normal around a fibre, and,

10 Figure 11 is a graph of the d-value in  $\mu\text{m}$  against the loss in dB/m for a D-fibre.

Referring to Figure 1, there is shown diagrammatically an optical communication system according to the invention which comprises a source 10 of light, light being passed by  
15 the source into an optical fibre 11. The source 10 can be a generally conventional source of optical light (usually of infra-red wavelength) which carries signal information and the optical fibre 11 may be of generally conventional construction and includes one or more discrete amplifiers  
20 12 or an amplifier which is distributed along the fibre itself.

The optical fibre includes antenna means 13 at spaced intervals along its length. The antenna means 13 comprises  
25 an extensive length of the optical fibre 11 which may be arranged so that light from within the fibre passes out of the fibre into free space. This may be done in a preferred arrangement by providing a length of the fibre formed as a "D-fibre" (the cross-section of which is shown in Figure  
30 2), that is, the cross section of the fibre is reduced from its normally circular cross section to a semi circular cross section by a transverse bisecting flat or planar surface 15. Such a construction is well known as a technique for removing light from the fibre and passing  
35 it to, for example, another fibre in contact therewith.

However in the present instance, such an arrangement is used to allow light to leak from the fibre 11 into free space.

5 It may be useful to provide typical values of the components described so far. Thus the antenna means 13 may be in the form of optical fibre of between 1 and 100 metre length, and the amount of light transmitted may be between 10mW and 1W. In a typical arrangement, the source 10  
10 be in the form of a laser which may provide 10mW, or 40mW power. Thus if the transmit means 13 comprises a 1 metre length of fibre, and it is desired to transmit 10mW of power, then if the laser has a power output of 40mW then the coupling between the core of the fibre and free space  
15 must be arranged so as to transmit a quarter of the power of the laser from the fibre evenly along that length of fibre.

As is well known, the so called "D"-fibre comprises a  
20 circular central core which is typically between 8 $\mu$ m and 10 $\mu$ m in diameter, of a glass of refractive index of the order of 1.454, surrounded by the D cross section cladding of glass of refractive index of 1.444 and of a diameter of about 125 $\mu$ m. This glass cladding is surrounded by a  
25 coating of plastic (polymer) of a refractive index so as to allow light from within the cladding to spill into the coating, and the coating can have a typical diameter of between 250 and 400 $\mu$ m, typically 350 $\mu$ m.

30 The d-value (the distance in  $\mu$ m from the periphery of the fibre core to the flat face) and/or the refractive index of the coating can be chosen to vary the power to be radiated from the fibre, and might be for example between about 1 and 25 $\mu$ m. For D-fire matching standard system fibre and a  
35 coating index of 1.584 (at 589nm), d-values have been

calculated which would provide fibre light losses of 0.05dB/m, 0.5dB/m and 10dB/m for use in various regimes. Thus for application of the optical communication system to a gallery or public area in which the distance might be 500m, the light loss required would be of the order of 0.05dB/m and this requires a d-value of about 22 $\mu$ m. In the case of application to offices, where the distance might be 50m, a light loss of 0.5dB/m would be typical and this will require a d-value of about 17 $\mu$ m. For a single emitter where the distance would be of the order of 5m, a light loss of approximately 10dB/m may be required which requires a d-value of approximately 11 $\mu$ m. Figure 11 illustrates the relationship in general terms between the loss of light per unit length along the fibre against d-value and the type of use which the different loss fibres would be applicable for a D-fibre of the values set out. These calculations have shown that the D-fibre type can be chosen to suit run-lengths of a few metres for point source applications, tens of metres for office environments and hundreds of metres for airport lounges or railway termini. (The light is required to leak out slowly, for long fibre runs, to maintain sufficient power along the length, whereas in the office environment the power can be released over a shorter distance.) D-fibre can be made using any of these values with no additional complexity in the manufacturing technique.

These results indicate that the using a large area photo-diode (50mm sq) with a dynamic range of 20dB and a sensitivity of -30dBm and a laser diode of 20dBm should provide a performance better than 16Mbit/s, for a non wavelength division multiplexed system (7).

Such values of d, refractive index, and diameters will be typical of the D-fibres described throughout this

specification.

In practice, in designing such a system, the starting point will be the relevant safety standard and this, when transmitted into the distance between a person and the transmit means, and the length of the transmit means, will indicate laser power required, and the efficiency of coupling between the fibre core and free space which is required in a particular circumstance.

If it is desired to allow escape of a lesser amount of light per unit length, the cross section may be greater than semi circular as shown in Figure 3, ie, the transverse surface 15 may be spaced from the longitudinal axis of the fibre 1 so that less material is removed from the fibre.

Whilst an arrangement as above described would work satisfactorily in many instances, because the light is passing down the fibre axially, although it leaks out from the fibre 11 into free space, it tends to form a cone around the axis of the fibre and the angle of the cone is not necessarily very great. It is desirable, and indeed may be in some circumstances essential to have a cone angle which is greater than that which would be provided by a simple D-fibre and thus steps are taken to provide more scattering of the light from the fibre.

As shown in Figure 4, there may be provided on or adjacent to the D-fibre section, means which we refer to as diffuser means 16 which provides a predetermined diffuse pattern of radiated light, and this diffuser means 16 may be in the form of scattering lenses (which may be formed, for example, of moulded plastic or may be formed by spraying transparent material onto the transverse flat surface 15, allowing the individual droplets to set and form lenticular



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elements which may be of random different focal lengths), a diffuse screen (which may be formed separately or may comprise a suitably roughened transverse flat surface 15), refractive lenses, or one or more holographic elements. Details of a holographic element suitable to the purpose is described in our copending European patent application no 92306894.4.

Alternatively, the transmit means 13 may comprise scattering centres on a round fibre, or coatings on a D-fibre with scattering centres as will be described later.

By virtue of the length of the exposed optical fibre 11 in the transmit means 13 and/or by virtue of the diffuser means 16 which as is illustrated in the Figures, scatters the light at an angle of more than  $90^{\circ}$  to the direction of passage of the light signal along the fibre, the effect is to create a diffuse distribution pattern of radiated light in free space which cannot be focused on to the retina or skin of a person with a lens in a manner such that the retina or skin can be damaged.

The transmit means 13 can be arranged to radiate light into free space in a diffuse manner but in a predetermined pattern as is indicated at 14. The patterns may overlap or be separated as is desired. In a particular arrangement, the optical fibre 11 may be arranged to traverse the ceiling of a room and patterns 14 covering the room may be provided.

Whilst we have referred to a plurality of separate transmit means spaced along the optical fibre, in certain circumstances it will be desirable to provide a long length of D-fibre and an optional associated diffuser element, to provide a lengthy transmit means. Indeed, the whole of the

optical fibre may be in the form of D-fibre so that a transmitter means is provided along its total length. Any of the thus far described arrangements of the invention may be used in this way.

5

In Figure 2, it will be seen that there is provided an arrangement similar to Figure 1 except that in place of separate transmit means, there is provided a single transmit portion 17 which is arranged in spiral form at the end of the optical fibre of D-fibre from which light is radiated from inside the fibre 11 into free space.

10

In the arrangement of Figure 1 the power level in the fibre 11 will generally drop exponentially along the length of the feeder run. This can be compensated by adjusting the dynamic range of the optical receivers associated with the respective transmitters 13, or by saturating the feeder 11 with optical power from the source 10 and amplifier 11. Another possibility would be to use binary related transmit means along the fibre 11 such that the amount of power that can be leaked at each transmit means 13 is progressively increased by a factor of 2. To avoid having a very high power source at one end of the feeder, it would also be possible to have a half power source at each end.

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A further arrangement for achieving more equal power distribution along the feeder 11 is shown in Figure 6 where like parts are denoted by the same reference numerals.

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In the arrangement of Figure 6, the feeder run 11 consists of an optical fibre doped with erbium ions, or with any dopant that produces optical amplification. It is then possible to pump the fibre at a shorter wavelength than the signal wavelength to excite the ions and thereby amplify the signal as it travels along the fibre. For example, a

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5 fibre doped with erbium ions and carrying a signal at 1500nm could be pumped at a wavelength of 980nm. The 1500nm signal is then coupled from the fibre at each tapping 13 while the pump power at 980nm is retained by the fibre for optical amplification. In this way, the signal strength can be maintained over an indefinite length.

10 The signals from the pump source 14 and the signal source 10 are coupled to the fibre 11 through a wavelength division multiplexer 15. By suitable choice of pump powers, doping densities, and rates at which the signal power is coupled out of the feeder, the distribution of coupled power along the feeder can be made essentially uniform.

15 Figure 6 shows a transverse section of a fourth embodiment of fibre for use with the invention.

20 Optical fibres are prone to breakage if put under tension, and it has become a well known technique to install optical fibres in a system by initially installing a conduit for the fibre which may be in the form of a tube. The conduit is of material which is not damaged by the inevitable bending and pulling which accompanies installation. Once  
25 the conduit has been suitably mounted, the optical fibre is fed along the conduit by means of a flow of air. Such a method is described in EP 0108590B. To assist in this process, it is known to provide on the outer surface of the optical fibre a coating of tiny glass beads (referred to as  
30 "ballotini") which has the effect of increasing the coupling between the flow or air and the fibre and improves the movement of the fibre through the conduit. Such a fibre unit and method for its preparation are described in our copending PCT Patent application WO93/01512 herein  
35 incorporated by reference.

We have discovered that there is a remarkable coincidence of mechanical and optical properties of the tiny glass beads in that they may be used to scatter light out of the optical fibre. Hollow ballotini are preferable for this application because they have the added advantage of greater scattering effect (more changes of refractive index are experienced by the light).

In use, ballotini (of diameter between 3 and 18  $\mu\text{m}$ ) are mixed with coating material having the same refractive index as the UV coating and are used to thinly coat a D-fibre (typically 82nm D-fibre) substrate. Figure 7 shows a cross section of the optical fibre thereby coated.

Where the apparatus is to be used in a distributed light system, a desired arrangement of transparent conduits is mounted across the ceiling of the room into which the light is to be transmitted.

The D-fibre is then blown into the conduit across the ceiling as described. The D-fibre orientation varies randomly along the transparent conduit and up to 50% of the available light is directed away from the useful direction for example towards the ceiling. Much of this wasted power can be regained by using a reflector behind the conduit.

In a test, a 1300nm, 1mw diode laser beam was launched into the D-fibre and a photo-diode was rotated radially around it to determine angles from the normal. Figure 10 shows the results of these measurements from which it will be seen that a lot of the light was scattered backwardly (ie, through more than 90° to the direction of passage of light through the fibre) as well as forwardly.

According to our calculations from the test results,

5 assuming the D-fibre is blown into a transparent ceiling conduit at a height of 2.5m, the arrangement provides illumination with a 3dB dynamic range at a desk height in an area 5m wide. The leakage rate is completely uniform along the fibre run direction.

10 The d-value (the distance in  $\mu\text{m}$  from the periphery of the fibre core to the flat face) and/or the refractive index of the primary coating, can be altered to vary the power to be radiated from the fibre. For D-fibre matching standard system fibre and a primary coating index of 1.584 (at 589nm), d-values have been calculated which can provide fibre light losses of 0.05dB/m, 0.5dB/m and 10dB/m for use in various situations. These calculations have shown that 15 the D-fibre type can be chosen to suit cable run-lengths of a few metres for point source application, tens of metres for office environments and hundreds of metres for airport lounges or railway termini.

20 In the arrangement shown in Figure 8, the ballotini are scattered throughout the fibre coating as well as towards the outside edge. This provides scattering from within the coating.

25 In the arrangement of Figure 9, there is provided a special fibre which has a much higher Rayleigh scattering coefficient than normal. The scattering properties of the fibre are enhanced by growing small crystals in the fibre core or by forming the fibre itself from a highly and 30 multiply doped silica glass. Thus such a fibre (which need not be a D-fibre) may be used to provide a leaky feed over 500 metres which scatters light out of the fibre at a rate of 40dB/km. The small crystals in the fibre core may be produced by controlled reheating of an optical fibre (or by 35 slowing cooling the optical fibre after manufacture)

through a temperature band between the glass transition temperature  $T_g$  and the crystallisation temperature  $T_x$  of the glass in question. A typical temperature band would be of the order of 500 to 1000°C and, depending upon the glass, the glass should be maintained in the desired temperature band for a period of time between less than one minute and one hour, typically one to two minutes.

Each of the arrangements described with reference to Figures 7 to 9 provides scattered light in a rearward direction with respect to the direction of the light along the fibre.

In another arrangement a length of D-fibre was fusion-spliced to the tail of a semiconductor communication laser of wavelength 1500nm. A silicon microlens array measuring 1cm<sup>2</sup> and containing 6400 lenses on a 250µm grid was placed, in optical contact, on to part of the D-fibre flat. The light emitted by the panel of microlenses is symmetrically distributed normal to the panel and spatially incoherent. The power thus distributed can therefore be higher, before safety considerations impose a limit, than is the case for direct laser or LED distribution. The power emission lobe has a 38°, 3 dB half angle. In fact, 80% of the input power from the laser diode was detected in the output lobe. It is calculated that this would transmit signals over a 4m width at desk level, from a ceiling height of 2.5m.

Quasi-continuous illumination could therefore be obtained by placing a microlens array every 4m along a cable run, spliced or connected into the transmission path. It is easy to imagine continuous distribution from suitably coated fibre, installed as a continuous length into a transparent conduit. This installation might be conveniently effected by the blown fibre technique for

installing fibre into preinstalled conduit.

5 If the light is being radiated along an extensive length of fibre, for example 2 metre, then the proportion of the light passing out of the fibre within a 5cm aperture will be 5/200 of the total light, although it is understood that there would be a greater amount of light transmitted from the fibre at the source end rather than the end remote from the source. This makes for inherent safety.

10

The arrangement of this invention has a multiplicity of uses.

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For example, in an office environment, the light transmitter may be provided in the form of the fibre 11 extending across the ceiling of a room, and a signal from the fibre 11 carrying broadcast information may be transmitted into the room from where it may be picked up by, for example, suitable receivers (such as light sensitive semiconductor elements) forming part of computers (such as portable computers) or televisions.

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The apparatus of the invention is particularly useful in circumstances where, for example, the information is either broadcast as above described or where there is considerably more information to be broadcast to the terminal than from the terminal. For example in an airline terminal or travel agent, it is necessary for each terminal to be able to access a lot of information about all of the timetables for a particular airline or whatever but the information which the terminal itself needs to send to the database is not great. Thus a very simple solid or radio link can be provided between the terminal and the database which can pass the necessary interrogation information at a relatively slow rate, but the data which the terminal

requires to answer the particular question can be considerable and this can be transported by a system of the invention at a very high data rate.

5 It is generally not necessary for the receiver of the television or computer to have a direct line of sight with the antenna means (13) but light reflected from other surfaces may be sufficient to provide sufficient signal to the television or computer receiver.

10

In another arrangement, an optical communication system in accordance with the invention may be provided remotely from houses or buildings and broadcast information, for example, television signals, may be broadcast to the houses or  
15 buildings from a remote location to be received by receivers.

20

Furthermore, the arrangement of the invention may be used in the common situation inside a theatre where an audio signal is impressed upon the light within the fibre and may be transmitted to a suitable headset.

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The invention is not restricted to the details of the foregoing example.



CLAIMS

1. An optical communication system for free space communication comprising an optical source including means to modulate the optical output to provide an optical signal, said optical source being connected to an optical fibre to pass said signal therealong, the optical fibre including antenna means comprising an optical fibre transmit portion comprising a core, and a cladding, said cladding including at least one substantially flat surface extending along its length and means to couple light out of the optical fibre through said substantially flat surface(s), and scattering means to incoherently scatter into free space light thus coupled out of the fibre.
2. An optical communication system as claimed in claim 1 characterised in that said optical fibre transmit portion includes a coating surrounding said cladding.
3. An optical communication system as claimed in claim 2 characterised in that the distance between said core and said flat surface and the relative refractive indices of the cladding and the coating is such that said optical signal from the optical fibre transmit portion is scattered into free space to provide incoherent scattered light outside the fibre.
4. An optical communication system as claimed in any of claims 1 to 3 characterised in that the light from within the optical fibre is scattered through an angle of more than  $90^\circ$  to the direction of passage of light along the fibre.
5. An optical communication system as claimed in any of claims 1 to 4 characterised in that the antenna means

includes means to further incoherently scatter the light into free space.

5 6. An optical communication system as claimed in claim 5 characterised is that the further scattering means includes a diffuser (16) in the form of a diffuse screen or scattering lens elements.

10 7. An optical communication system as claimed in claim 6 characterised in that said scattering lens elements are lenticular elements formed by spraying transparent material on to at least one of said at least one flat surface and allowing individual droplets to set.

15 8. An optical communication system as claimed in claim 5 characterised in that the further scattering means comprises glass beads.

20 9. An optical communication system as claimed in claim 8 characterised in that the glass beads have diameters in the range of 3 to 18 $\mu$ m.

25 10. An optical communication system as claimed in claim 2 and 8 or 9 characterised in that the coating is transparent to said light and said glass beads are provided within the coating or on the outer surface of the coating of both.

30 11. An optical communication system as claimed claim 5 characterised in that the further scattering means comprises irregularities in the core of the fibre.

35 12. An optical communication system as claimed in claim 11 characterised in that the irregularities comprise crystals within the fibre core which provide Rayleigh scattering.

13. An optical communication system as claimed in claim 5 characterised in that the further scattering means comprises a holographic element.

5 14. An optical communication system as claimed in claim 13 characterised in that said holographic element is formed on at least one of said substantially flat surface of said fibre.

10 15. An optical communication system as claimed in any of claims 1 to 14 characterised in that a plurality of said optical fibre transmit portions (13) are provided at spaced intervals along the optical fibre.

15 16. An optical communication system as claimed in claim 15 characterised in that said spaced optical fibre transmit portions (13) are arranged so that, successive portions are arranged to transmit an increasing proportion of the available light in the fibre whereby the amount of light  
20 transmitted by each portion is substantially the same.

17. An optical communication system as claimed in any of claim 16 characterised in that the optical fibre transmit portion is between 1 and 100m in length.  
25

18. An optical communication system as claimed in claim 16 characterised in that the optical fibre transmit portion is between 1 and 10m in length.

30 19. An optical communication system as claimed in claim 17 or 18 characterised in that the optical source is arranged to transmit an optical signal of 10mW to 1W along the optical fibre.

35 20. An optical communication system according to any of

claims 1 to 19 characterised in that the optical fibre (11) includes a dopant capable when stimulated of amplifying the signal from the source (10) as the signal travels along the fibre.

5

21. An optical communication system according to claim 20 characterised in that the optical source (10) and a pump source (14) are connected to the fibre (11) through a wavelength multiplexer (15), the pump source (14) providing a signal at a shorter wavelength than the signal from the optical source (10) to stimulate the dopant in the fibre.

10

22. An optical communication system as claimed in claim 1 and 5 and 19 characterised in that the source is a laser having a power output up to 200mW and in that the light transmitted from the optical communication system is arranged so that it is not possible, with a lens of up to 50mm diameter, to focus the light to provide an energy density sufficient to damage a human as defined.

15

20

23. An optical communication system as claimed in any of claims 1 to 22 characterised in that the distance (d) between the periphery of said core and said substantially flat surface of the cladding is between 1 and 10 $\mu$ m.

25

24. An optical communication system as claimed in claim 23 characterised in that the distance (d) between the periphery of said core and said substantially flat surface of the cladding is approximately 5 $\mu$ m.

30

25. An optical communication system as claimed in any of the preceding claims characterised in that said cladding is surrounded by a coating of diameter in the range 250 to 400 $\mu$ m.

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26. An optical communication system as claimed in claim 25 characterised in that said cladding is surrounded by a coating of diameter in the range approximately 350µm.

5 27. An optical communication system for free space communication comprising an optical source, including means to modulate the optical output to provide an optical signal, said optical source being connected to an optical fibre to pass said signal thereto, the optical fibre  
10 including signal transmit means comprising an optical fibre transmit portion comprising a core, and cladding, the core including optically effective irregularities whereby some of said optical signal from the optical fibre transmit portion is scattered through the cladding to provide  
15 incoherent scattering into free space outside the fibre.

28. An optical communication system as claimed in claim 27 characterised in that said irregularities comprise small  
20 crystals within the fibre core which provide Rayleigh scattering.

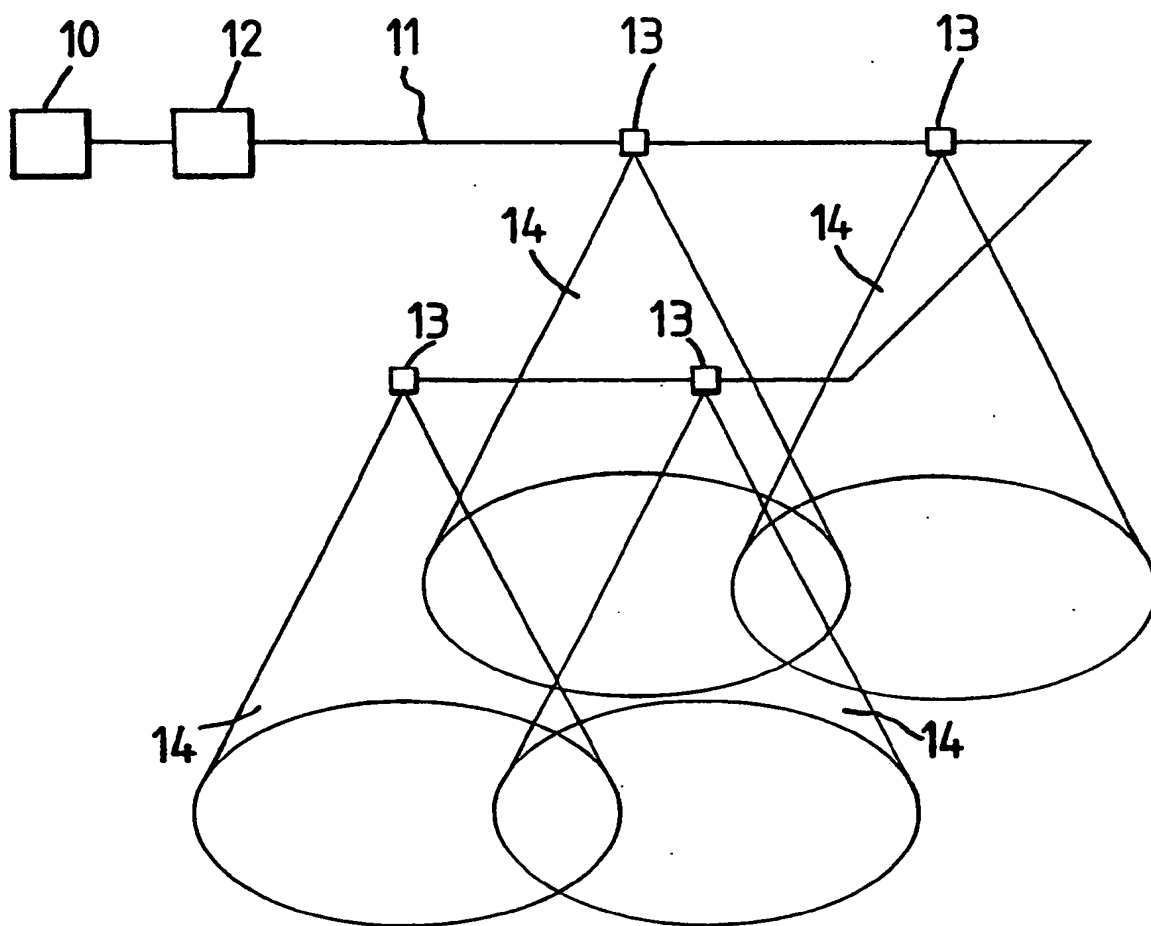


FIG 1

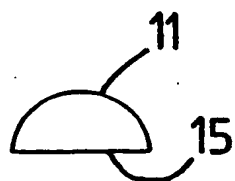


FIG 2

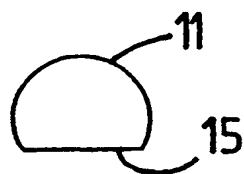


FIG 3

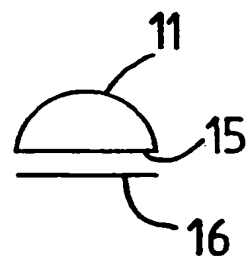


FIG 4

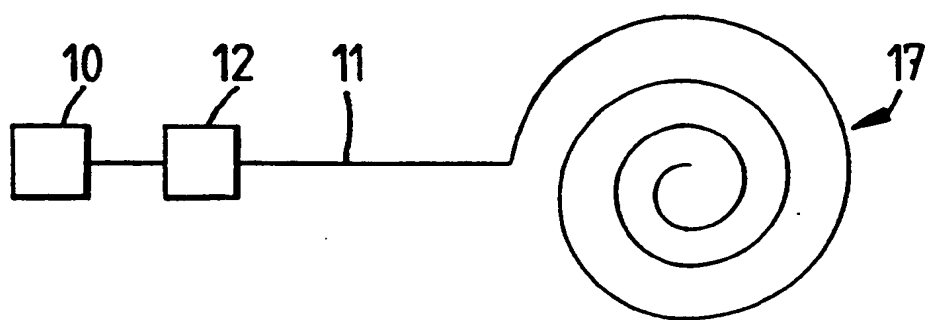


FIG 5

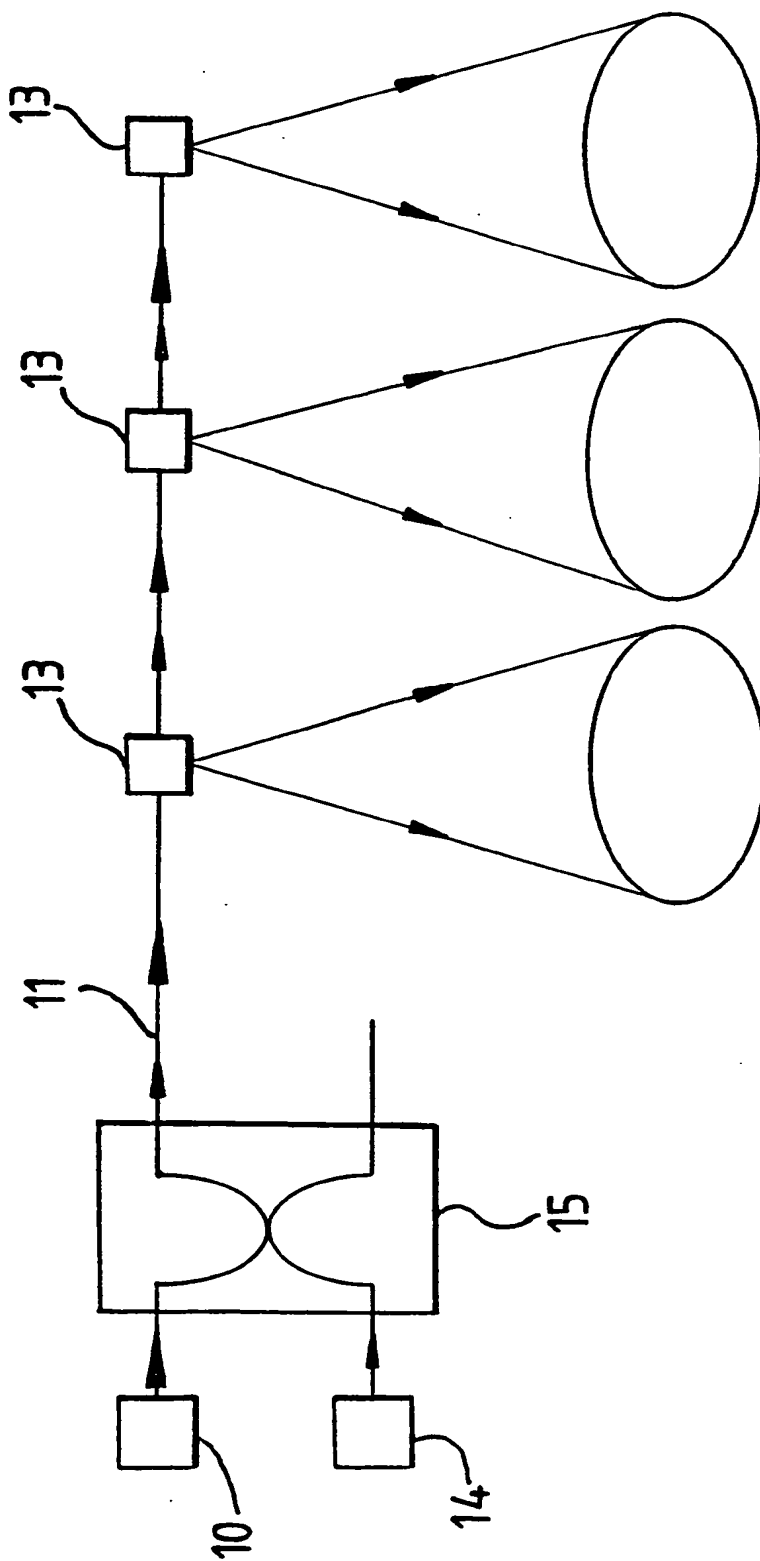


FIG 6



4/6

FIG 7

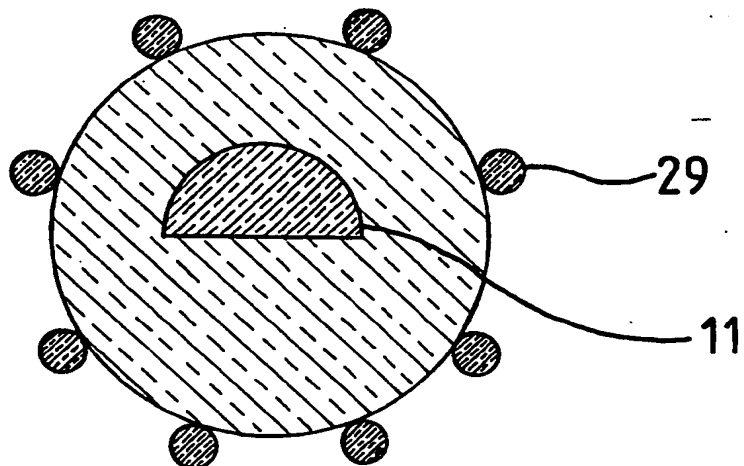


FIG 8

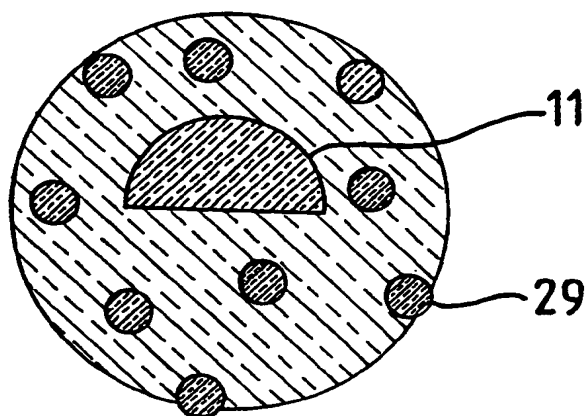
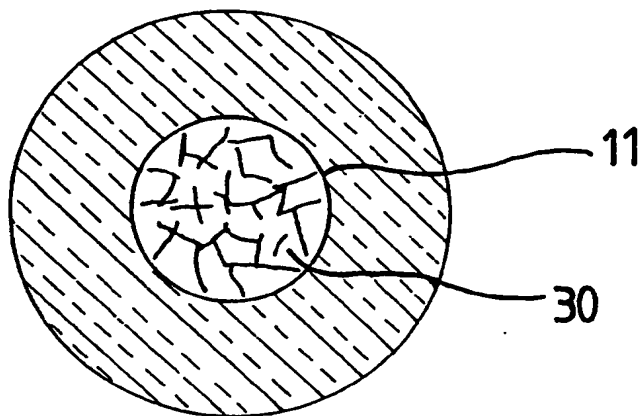


FIG 9



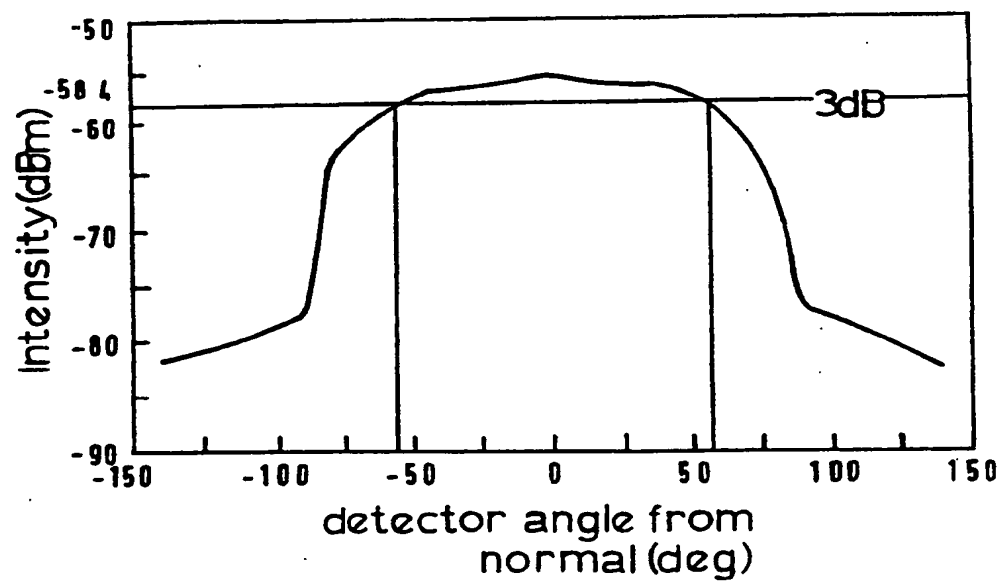


FIG 10

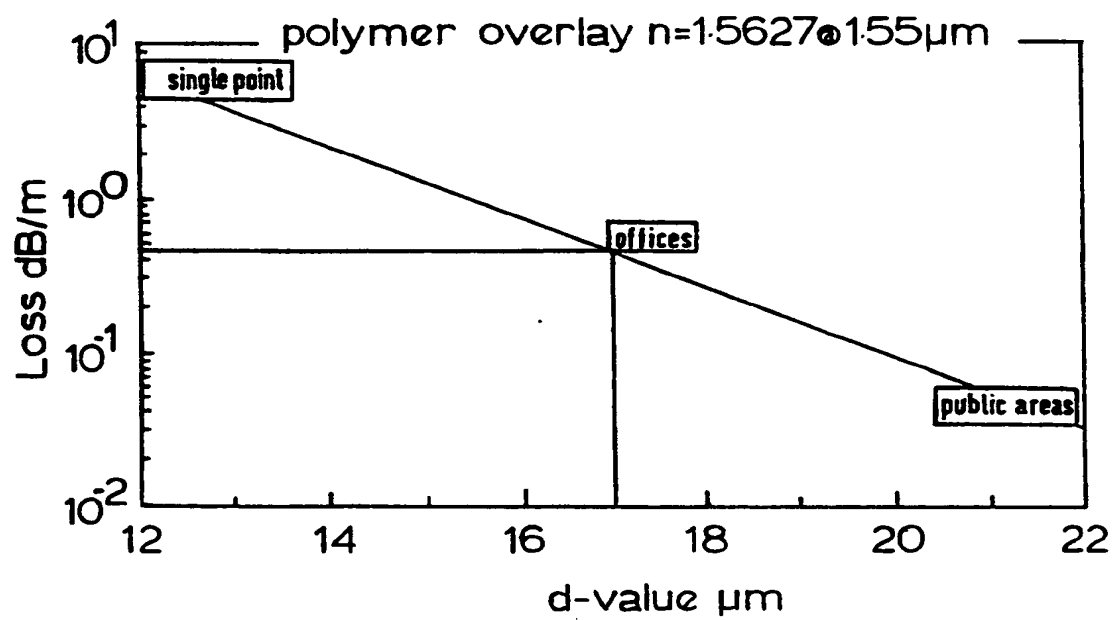


FIG 11

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 93/01590

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 5 H04B10/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 H04B G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 398 181 (STANDARD ELEKTRIK LORENZ) 22 November 1990 see column 2, line 29 - line 31 see column 2, line 49 - line 51 see column 3, line 14 - line 19 see column 3, line 37 - line 54 see column 4, line 4 - line 9; figures 3,5 ---	1-28
A	EP,A,0 188 085 (STC) 23 July 1986 see the whole document --- -/--	1-28

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## \* Special categories of cited documents :

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\*O\* document referring to an oral disclosure, use, exhibition or other means

\*P\* document published prior to the international filing date but later than the priority date claimed

\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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\*&amp;\* document member of the same patent family

Date of the actual completion of the international search

4 November 1993

Date of mailing of the international search report

26. 11. 93

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 93/01590

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ELECTRONICS LETTERS. vol. 26, no. 22 , 25 October 1990 , STEVENAGE GB pages 1909 - 1910 ACHURCH 'Optical tap based on D-fibre' see page 1909, right column, line 14 - line 16 see page 1909, right column, line 21 - line 24; figure 1 -----	1,3,23, 24
A	PATENT ABSTRACTS OF JAPAN vol. 13, no. 497 (M-889)1989 & JP,A,01 197 902 (ASAHI GLASS) see abstract -----	1-14, 23-26

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 93/01590

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0398181	22-11-90	DE-A- 3915977	29-11-90
EP-A-0188085	23-07-86	GB-A- 2169464	09-07-86
		JP-A- 61191132	25-08-86